EXHIBIT A

SCOPE OF WORK

ATTACHMENT 1:

GROUNDWATER AVAILABILITY MODELING PROGRAM GUIDELINES

Changes from Previous Requests

This is the sixth Request for Qualifications for the groundwater availability modeling (GAM) program concerning model development. Based on the guidance of our technical advisory group, internal process improvements, and the unique nature of the systems to be modeled, we have made some changes to the previous versions of the Request for Qualifications. The following summarizes what we perceive to be the major changes to previous versions of Request for Qualifications. This summary is not meant to be comprehensive—applicants are ultimately responsible for being familiar with the content of the Request for Qualifications.

- Access and maintenance of stakeholder advisory forums has been changed, as well as requirements for deliverables to be accessible for the visually and hearing impaired. All deliverables shall comply with federal accessibility regulations (Section 2.0).
- Model grids are expected to be 1/8 miles or finer to adequately simulate the narrow Brazos River Alluvium Aquifer.
- At least two numeric layers are required to simulate the vertical flow in the alluvium.
- Model extent should be expanded laterally beyond the alluvium aquifer and vertically with additional model layer(s) if significant groundwater connection exists between the Brazos River Alluvium Aquifer and adjacent aquifers or other hydrogeologic units.
- Previously published studies by U.S. Geological Survey (http://pubs.usgs.gov/sim/2989/) (Shah and others, 2007) should be considered for development of the hydrostratigraphic framework (Section 3.1.4). In this study, the hydrostratigraphic framework has a grid interval of 1/2 miles. If the hydrostratigraphic framework by U.S. Geological Survey is not adequate to create 1/8 mile or finer grid intervals, the contractor shall re-produce the finer hydrostratigraphic framework using all available data
- BRACs database developed by TWDB and other resources should be reviewed and evaluated for any useful information.
- The models shall all use MODFLOW-2000 or more recent MODFLOW codes with pre-approval from TWDB contract manager. The model developed should be capable of linking with surface water model at a future date (Section 3.2).
- New software requirements: Groundwater Vistas (version 6.0) and ESRI Arc/GIS (10 or 10.1) (Section 4.1).
- Clarified and updated deliverables for conceptual report/data, final draft report/data, and final report/data (Section 4.4.3).
- Restructuring of report(s) (Section 4.4.1).
- In addition, there shall be an accounting of the number of cells that change from artesian conditions to water table conditions and the number of cells that go dry during a simulation,

if applicable.

Contents

1.0 Introduction

One of the purposes of the Groundwater Availability Modeling (GAM) Program is to provide scientific analyses of policy-derived desired future condition of aquifers determined by the groundwater conservation districts in sixteen groundwater management areas across Texas. The groundwater availability modeling effort will result in numerical computer models and supporting data sets of the major and minor aquifers in Texas. The groundwater availability modeling process will include substantial stakeholder input and will result in standardized, thoroughly documented, and publicly available numerical groundwater flow models and supporting information. The models, source information, and final reports will be provided to the Texas Water Development Board (TWDB) for posting and distribution on the Internet or via other electronic means.

This attachment to the request for qualifications has considerable details because of:

- Need for standardization between the different models
- Planned public dissemination of the models, supporting information, and results
- Assurance that the TWDB receives deliverables that meet program requirements

Where appropriate, we have added specific requirements for specific aquifers and models. The major subheadings below (Stakeholder Participation, Model Development, Documentation, Project Management, and Project Schedule) list TWDB expectations and requirements for the modeling projects. Executed contracts for these modeling efforts will parallel the requirements described in this document.

2.0 Stakeholder participation

Stakeholder participation is critical to the success of the groundwater availability modeling program and the development of the models. This includes participation from all levels of the public and private sector including Regional Water Planning Groups, Groundwater Conservation Districts, Texas Commission on Environmental Quality, Texas Parks and Wildlife Department, Texas Department of Agriculture, water utilities, educational, agricultural, environmental, private landowners, industry, and groundwater consultants. These groups will be relied upon to voice issues and provide information that will ensure that the models can address the important water resource questions for each aquifer. It will be the contractor's responsibility to meet with a Stakeholder Advisory Forum of the above stakeholders and hold key milestone meetings to discuss progress of the modeling effort and to solicit stakeholder comments. It is extremely important that regional water planning groups and groundwater conservation districts be informed about the models because they will use these models to assess groundwater availability or evaluate water management strategies. The contractor shall work with the TWDB in developing the initial invitation list for the stakeholder advisory forum. Stakeholder advisory forum attendees will participate voluntarily with no compensation. The modeling projects will have a stakeholder advisory forum database maintained through TWDB staff.

Stakeholder advisory forums will be open to the public. The contractor shall work with the TWDB contract manager or other appropriate TWDB staff to coordinate meeting dates and locations. It will be the contractor's responsibility to notify the stakeholder advisory forum participants of upcoming meetings. The preferred method of notification will be by email. Stakeholder advisory forum participants without email or with a preference other than email will be notified by letter. Stakeholder advisory forum participants with email shall be notified at least 21 days before the meeting and reminded again at least 7 days before the meeting. Stakeholder advisory forum participants that have to be or prefer to be notified by letter will be mailed one notice at least 21 days before the meeting. The stakeholder advisory forum notice will include information about the meeting as well as an outline of what will be discussed at the meeting. The first stakeholder advisory forum shall be a general meeting no more than two months after the contract starts that describes:

- Basics of groundwater flow in the aquifer
- Concept of numerical groundwater flow modeling
- Experience from previous models of the aquifer, if applicable
- Planned approach for modeling the aquifer
- Request for local scientific data and model input information
- Proposed schedule for the project
- Expectations of the model (what the model will or will not do) shall also be discussed

It will be extremely important to provide a well-defined schedule to the stakeholders on when input and data are needed for the model. In this way, stakeholders' expectations can be managed and contractors will not have to work with late arriving data. At a minimum, the remaining stakeholder advisory forums should be scheduled as follows:

- After the conceptual model portion of the project has been completed
- After the model has been calibrated

Additional stakeholder advisory forums may be scheduled at the contractor's discretion. Contractors shall submit copies of the stakeholder advisory forum PowerPoint presentations to the TWDB contract manager to preview at least 48 hours prior to the scheduled SAF meeting. Presentations need to be easy to understand and informative to a non-scientific audience as much as possible. Although attendees are generally knowledgeable about groundwater, most do not hold degrees in geology, hydrology, engineering, or geostatistics. However, technically minded stakeholders shall be encouraged to ask technical questions and contractors shall answer these questions at the same technical level of the question. In addition, technical questions should also be 'translated' for the non-technical audience.

After each meeting the contractor shall submit:

- Memo report
- Copy of the stakeholder advisory forum presentation
- Attendance sign-up sheet

Memo reports (submitted to TWDB in Word and Adobe Acrobat-compatible formats) will summarize the presentation, the questions and issues that arose from the stakeholder advisory forum attendees, and how the questions were or will be addressed. These memo reports will be posted by the TWDB on the TWDB web page for public viewing.

Digital copies of final presentations at each stakeholder advisory forum meeting (in both PowerPoint and Adobe Acrobat compatible formats) shall also be given to the TWDB for posting on the web within two business days of the stakeholder advisory forum meeting. The documents should be accessible for people with disabilities, i.e. all figures tagged, identified language as English, et cetera. For easier website accessibility and due to e-mail limitations, the Adobe Acrobat-compatible format deliverables should not exceed 10 megabytes in size. Therefore, some deliverables may need to be submitted in parts.

An attendance sign-up sheet shall be provided at each meeting. The list of attendees and their affiliation shall be given to TWDB for posting on the TWDB web page for each stakeholder advisory forum. New and revised stakeholder contact information shall be reviewed and updated, as applicable, and provided to the TWDB contract manager for updating the stakeholder advisory forum database.

There will be a one day-long seminar for TWDB staff and at least one day-long seminar for stakeholders to learn how to use the model after the model is finished and the draft report has been submitted, if needed.

3.0 Model development

The basic steps in model development and completion include:

- Developing the conceptual model
- Defining the model architecture
- Calibrating the model
- Conducting sensitivity analyses

3.1 Conceptual model

The conceptual model is a description of the best understanding of how groundwater moves through the aquifer system. In developing the conceptual model, the information necessary for developing the numerical model is compiled, organized, and described. The conceptual model shall include information on:

- Physiography and climate
- Geology
- Hydrostratigraphy
- Hydrostratigraphic framework
- Water levels and regional groundwater flow
- Recharge
- Rivers, streams, reservoirs, springs, and other surface hydraulic features
- Hydraulic properties
- Discharge
- Water quality

During the development of the conceptual model, the TWDB (including the Texas Natural Resources Information System), Texas Commission on Environmental Quality, Regional Water Planning Groups, Texas Parks and Wildlife Department, Texas Railroad Commission, U.S. Geological Survey, groundwater conservation districts, river authorities, or other appropriate entities shall be contacted for relevant information. Published papers and reports on the aquifer shall be compiled, reviewed, and documented. Earlier modeling efforts on the subject aquifer or adjacent aquifer(s) shall be thoroughly reviewed and documented.

Development of the conceptual model and any information entered into the numerical model shall only use publicly available information or information that can be made publicly available at project completion. Each element of the conceptual model shall be thoroughly described, documented, and referenced in the final report (see Section 4.0). In addition, any assumptions shall be stated and adequately justified. Development of the conceptual model shall be based on documented field data as much as possible or published work. The conceptual model shall be visually summarized with a block diagram demonstrating major components of flow in the aquifers (that is, recharge, cross-formational flow, flow directions). See Section 4.4 for requirements of the final report.

3.1.1 Physiography and climate

Physiography (the study of physical features of the Earth's surface) and climate of the study area shall be described and include descriptions and maps or graphs of:

- Physiographic delineations and features
- Topography
- General climate characteristics
- Spatial and temporal variability of precipitation
- Spatial and temporal variability of temperature
- Spatial and temporal variability of evaporation
- Evapotranspiration

This section shall also describe the aerial extent of the study area. Because of the significance of evapotranspiration for this study area, this section should also include research on vegetation and soil properties as it relates to evapotranspiration.

3.1.2 Geology

The general geology and structural geology of the study area shall be described and include:

- Detailed stratigraphic chart
- Description of each of the geologic formations that includes the formation thickness characteristics, depositional environment, and rock composition
- Map of the surface geology
- Several cross sections throughout the study area
- Brief discussion of the geologic and tectonic history including regional and local structural features

3.1.3 Hydrostratigraphy

Hydrostratigraphy (the layering of aquifers and confining units) for the study area shall be presented and discussed. The discussion shall include:

- Detailed hydrostratigraphic chart
- Rationale for the hydrostratigraphic units
- At a minimum, the hydrostratigraphic units that underlay or interact with the alluvium
- Any exceptions and additions should be thoroughly documented and pre-approved by TWDB staff

3.1.4 Hydrostratigraphic framework

The hydrostratigraphic framework shall describe the elevation of the top and bottom of each of the hydrostratigraphic units. For each layer in the model, an elevation map of the top and bottom shall be generated that includes the location of the data used in the interpolation. Land-surface elevations shall be used as the top of the model domain. Land-surface elevation shall be defined by USGS 1/3-arc-second (10-meter) or appropriate digital elevation models (DEMs). Layer thickness maps shall also be developed. Information considered for the hydrostratigraphic framework shall include information derived from a previous contracted study with the U.S. Geological Survey (please see http://pubs.usgs.gov/sim/2989/) (Shah and others, 2007). If this hydrostratigraphic framework is not adequate to create the finer grids, contractor should re-produce the hydrostratigraphic framework using all available data. All information used to develop the hydrostratigraphic framework surfaces shall be fully documented as to data source, data interpolation techniques, and data quality.

3.1.5 Water levels and regional groundwater flow

Water levels and water-level maps describe general groundwater flow directions, hydrologic boundaries, and provide information for the calibration of the model. At least four water-level maps shall be generated for each of the hydrostratigraphic units included in the model:

- Predevelopment conditions (for the steady-state model)
- For the beginning of the transient calibration period
- During the transient calibration period (at a time-period chosen in cooperation with the TWDB)
- For the end of the transient calibration period (information on the transient calibration period is included in Section 3.3)

The predevelopment maps shall be based on historical water-level information, but may include older or more modern information to help guide water-level interpretation. Long-term historical hydrographs shall also be developed for the study area, as the data permit. These hydrographs will help define water-level fluctuations throughout the model area, and will also serve as calibration targets for the transient model.

Contractors shall document and describe the following, if appropriate:

- Hydraulic-head differences between hydrostratigraphic units
- Nature of the vertical connection between hydrostratigraphic units
- Areas of water-level declines
- General water-level behavior in the aquifer

Regional groundwater flow paths shall be identified as well as any features that affect flow paths such as surface-water/groundwater interaction, faulting, and cross-formational flow. Any information on cross-formational flow shall also be investigated, documented, and discussed.

3.1.6 Recharge

Texas Water Code §36.001, subdivision 26, defines recharge as the amount of water that infiltrates to the water table of an aquifer. Depending on the aquifer, this may include precipitation infiltrating by percolation, irrigation return flow, and stream losses. Previously published estimates of recharge for the aquifer shall be compiled and assessed using Scanlon and others (2002) as a guide. Important factors related to how the aquifer is recharged and effects of seasonal variations shall be examined and discussed. Recharge shall be distributed according to infiltration characteristics of the aquifer (for example, soil properties, water table depth, and topography), precipitation rates, and losing streams, if applicable. Maps of recharge potential or recharge coefficients (for example, see Mace and others, 2000) shall be generated for the model area.

Recharge can be influenced by water table fluctuation due to seasonal change or groundwater extraction. As a result, the conceptual model and the numerical model must include the concept and effect of 'rejected recharge' (for example, see Theis, 1940, summarized in Domenico and Schwartz, 1990, p. 200-202). Although some of the past models may have successfully simulated current or historical aquifer conditions without considering rejected recharge, groundwater availability models should realistically predict the effect of large cones of depression on local flowpaths (that is, capture of rejected recharge) in the aquifer. Therefore, the models should be capable of simulating changing flow patterns due to changing aquifer conditions. This may be accomplished by modeling evapotranspiration and surface water/groundwater interactions, for example.

3.1.7 Rivers, streams, springs, and reservoirs

Surface hydraulic features, such as rivers, streams, springs, and reservoirs, can interact with groundwater and thus must be addressed. The primary surface hydraulic features in the model area shall be identified and described along with historical flows. For rivers and streams, reaches with net gains and losses shall be identified and, if possible, quantified. TWDB-funded research on surface water/groundwater interaction (Slade and others, 2002) and the gain/loss study by the U.S. Geological Survey (Turco and others, 2007) must be incorporated into the analysis, as applicable. Any specific or general information on streambed conductance shall also be addressed. Elevations of riverbeds, streambeds, spring orifices, and reservoir levels shall be determined from the best-documented available sources. Information needed for the MODFLOW streamflow-routing package (Prudic and others, 2004) shall also be correctly estimated and discussed (that is, streambed top and bottom, channel width and slope, and Manning's roughness coefficient). Information needed for the MODFLOW reservoir package (Fenske and others, 1996) shall also be estimated and justified (for example, reservoir conductance, cell-to-cell connectivity, and reservoir levels), as applicable. All surface-water features that are important elements of the hydrologic flow system shall be incorporated into the model with an appropriate MODFLOW package.

3.1.8 Hydraulic properties

Hydraulic properties of hydrostratigraphic units that help define the flow characteristics of the aquifer must be addressed. These include the transmissivity, hydraulic conductivity, storativity, and specific yield. Results from available aquifer tests for the model area shall be compiled and assessed including information from a previous contracted report with the U.S. Geological Survey (Shah and Houston, 2007) and any information from the groundwater conservation districts. Specific capacity tests shall also be compiled from TWDB files, and from Texas Commission on Environmental Quality files, and transmissivity and hydraulic conductivity estimated using analytical or empirical techniques (for example, Mace, 2001). Contractors are encouraged to conduct, analyze, and use **additional aquifer tests,** if they believe the budget can support them.

Transmissivity, hydraulic conductivity, storativity, and specific yield shall be statistically analyzed for each hydrostratigraphic unit. Special care must be taken in considering the completion zones of the test wells and how they relate to the aquifer. Maps of the spatial distribution for these properties shall be presented for each hydrostratigraphic layer using the appropriate interpolation techniques given the amount of data and apparent trends (for example, geostatistical techniques). If the information is available, hydraulic properties shall be related to and distributed according to the known geologic characteristics of the aquifer (for example, texture and net-sand thickness possibly associated with cut banks and point bars). Specific or general information on vertical hydraulic conductivity for each layer shall be compiled and/or calculated and related to known geologic and hydrogeologic conditions. If possible, vertical hydraulic conductivity and storativity shall be distributed according to geologic information (for example, texture, net-sand thickness, and horizontal beddings). Horizontal anisotropy shall also be defined, discussed, and estimated, if appropriate.

3.1.9 Discharge

Discharge describes the flow of water out of the aquifer either through cross-formational flow; baseflow to streams, springs, or other surface-water bodies; and pumping. Cross-formational flow, baseflow to streams, and discharge to springs shall be identified, discussed, and, if possible, quantified (surface hydraulic features are discussed in Section 3.1.7). Additional information regarding historical pumping from the groundwater conservation districts located in the study area shall be requested, reviewed, and used, as applicable. It is the contractor’s responsibility to use the existing models, associated data, and other public data sources to quantify the groundwater discharge.

3.1.10 Water quality

Although the models will not explicitly model water quality and solute transport, it will be important to document water quality of the aquifer so later users can more accurately gage groundwater availability. Therefore, total dissolved solids and other constituents of concern shall be presented as part of the conceptual model. In addition, water chemistry data may also help identify the groundwater sources and pathways and research is encouraged. As a result, water quality data should be used and documented in previous sections, as appropriate.

3.2 Model architecture

The models shall all use MODFLOW-2000 or a more recent MODFLOW code with pre-approval from the TWDB contract manager. This model shall be designed so in the future a compatible surface water model can be linked such as MODBRANCH, PRMS, or SWAT. All models will use MODFLOW components that are freely available (that is, proprietary modules or codes shall not be used). However, the final model (including supporting graphics) shall be fully compatible with Groundwater Vistas 6.0, a proprietary pre- and post-processor to the MODFLOW code. The final model shall be able to run on a personal computer under the Microsoft Windows-7. Length units for model input will be in feet and time units will be in days.

3.2.1 Cell size, orientation, layering, and parameter assignment

Given the width of the alluvium and potential coupling with a surface water model in the future, the lateral cell size shall be **no greater than** 1/8-mile by1/8-mile for the Brazos River Alluvium. Cells representing adjacent aquifers may be gradually increased by a factor of no more than 1.5 with a maximum cell size no more than one square mile. The grid shall be oriented with the prominent alluvium deposit and/or regional groundwater flow paths, as much as possible.

To simulate the vertical flow in the alluvium, at least two numerical layers should be used for the Brazos River Alluvium. If the hydraulic connection between the alluvium and underlying unit(s) is proven significant, then addition model layer(s) should be used to simulate the underlying unit(s). If the lateral flow between the alluvium and the adjacent unit(s) is proven significant, then the numerical layers should be extended to incorporate the adjacent unit(s). The hydrostratigraphic framework shall include metadata that delineates aquifers. Hydraulic properties of the adjacent unit(s) shall be identified and used to define that portion of the active model layer(s). It is the contractor's responsibility to use the data from the previous contracted report with the U.S. Geological Survey (Shah and Houston, 2007) and other information to refine the model cells and their hydraulic properties laterally and vertically. All numerical layers are expected to be convertible unless directed by TWDB otherwise.

Hydraulic property values used for model construction should be based on field measurements and consistent with the conceptual model. It is the contractor's responsibility to review all available data and to correctly define the hydraulic property values. If certain properties are assigned to the model on cell-by-cell basis, then spatial data shall be interpolated to model cells using an appropriate interpolation procedure. For MODFLOW-2005 family codes, the contractor must identify whether the storativity or specific storage is used. And, for the latter, the contractor must document how the specific storage is calculated.

An HDRY value of 9999 should be utilized to indicate cells that convert to dry.

3.2.2 Recharge and surface water

It is extremely important that recharge and surface-water/groundwater interaction be modeled in a realistic manner appropriate for historical and future predictive conditions. Constant head cells in recharge zones will not be accepted as an appropriate final method of simulating recharge. The contractor must obtain written permission from the TWDB to use a package other than the MODFLOW Recharge package to simulate recharge in the groundwater availability model. The chosen method shall provide recharge for local as well as regional flowpaths and allow for local discharge. The method chosen for simulating recharge must include the concept and effect of rejected recharge as discussed in Section 3.1.6. A recharge method that includes rejected recharge will allow the effective recharge (or flow) to the confined aquifer to increase as water levels decline. Some MODFLOW packages to consider, depending on scale and flow conditions, may include:

- MODFLOW-2000 or later version Evapotranspiration (EVT) Package
- Evapotranspiration Segments (ETS1) Package
- MODFLOW streamflow-routing (STR1) package (Prudic and others, 2004)
- MODFLOW-2000 or later version Drain (DRN) Package
- Drain Return (DRT1) Package

This is extremely important for realistically modeling the effects of withdrawals on water levels in aquifers. Contractors must consider that recharge rates may have changed over time owing to changes in land use and irrigation return flow.

All important surface hydraulic features, such as rivers, streams, springs, reservoirs, and wetlands, shall be included in the model and considered realistically, using the appropriate MODFLOW package (for example, the streamflow-routing or river package for rivers and streams and the drain package for springs,). Contractors may use the River or Drain package for rivers and streams if they can demonstrate to TWDB staff that model predictions will not be affected. Similar to recharge (see Section 3.1.6), it is extremely important that rivers and streams are simulated realistically if water levels in the aquifer fall below the base of these rivers or streams (for example, they produce realistic downward fluxes of water).

3.2.3 Model extents and boundaries

The lateral extent of the models should follow natural boundaries as much as possible. The submitted proposal and report shall describe the rationale for the boundaries in the model. At a minimum, the lateral extent of the model shall include the official Brazos River Alluvium Aquifer and the adjacent Brazos River. If lateral flow between the alluvium and the adjacent hydrogeologic unit(s) is or will be significant under pumping conditions, then the lateral extent of the model should be extended. The model should be also extended vertically to include the hydrogeologic unit(s) if a significant hydraulic connection exists between the alluvium and the underlying unit(s).

3.2.4 Pumping

Groundwater pumpage shall be defined and assigned, as applicable, according to TWDB water-use categories: industrial (manufacturing), power, mining, irrigation, municipal, livestock, and rural domestic (county other). It is the contractor's responsibility to evaluate the pumping data from the TWDB water use survey and adjust them, if necessary, so that the groundwater pumping is simulated correctly by the model. Contractor should document why and how the adjustment is made. Contractors are also required to retain regional water planning water user group (WUG) identification fields throughout data processing and the spatial assignment of pumpage, as much as possible. Standardized water user group identification fields and data that shall be retained include:

- WUG_ID
- WUG_NAME
- DATA_CAT
- WUG_RWPG
- WUG_COUNTY_NAME
- WUG_BASIN_NAME
- CITY_ID
- WUG_COUNTY_ID
- WUG_BASIN_ID

3.3 Model calibration

The model should be calibrated for both steady-state and transient conditions:

- The steady-state calibration shall be performed to predevelopment conditions as defined in Section 3.1.5. The mean absolute error between measured hydraulic-head and simulated hydraulic head shall be less than 10 percent of the measured hydraulic-head drop across the model area for each model layer. The error shall not be spatially biased (e.g., not towards areas with more control points than others). Final calibration results shall report the mean absolute error, the mean error, and standard deviation. The difference between the total simulated inflow and the total simulated outflow (that is, the volumetric mass balance) shall be less than one percent and ideally less than 0.1 percent for each model layer in each county. Initial parameters for the models shall be derived from the data generated during the development of the conceptual models. Parameters adjusted during calibration (for example, recharge, hydraulic conductivity, and vertical hydraulic conductivity) shall be within defensible limits within the framework of the conceptual model such that the resulting model has realistic values and realistic spatial distributions of parameters. Any changes to model parameters must be thoroughly documented in the final report. If unrealistic hydrologic parameters must be used to calibrate the model or the model cannot be calibrated to the above mean absolute error for matching hydraulic head or the error on the water balance, the contractor shall meet with TWDB staff to discuss how to proceed with the model. The TWDB shall not accept over-calibrated models.

- The transient model shall start with the steady-state model and stop at the end of the most recent year. Stress periods may be of variable length according to the density of information on pumping and recharge, but the stress periods for the transient calibration period shall not be greater than 1 year. Particular attention shall be paid to represent water levels and fluxes accurately during times of drought and in areas with large drawdowns. Mean absolute error between measured hydraulic head and simulated hydraulic head should be less than 10 percent of the maximum hydraulic-head drop across the model area for head targets in all transient stress periods and better, if possible, at the calibration periods selected in cooperation with the TWDB and at the end of the transient calibration period. The range of water-level fluctuation in the observation wells shall be matched as closely as possible during the transient calibration. Long-term hydrographs comparing measured hydraulic head and simulated hydraulic heads shall be developed and included in the report. The location of the wells used to generate the hydrographs should not be spatially or vertically biased; however, as much as possible the wells selected should provide enough coverage to analyze the calibration of the model on a county level. A plot of the residuals and data points during and at the end of the transient calibration period shall be made for each layer and included in the final report. Larger known fluxes out of the aquifer (for example, springs and baseflow to streams) shall also be used during the model calibration and if possible shall be matched to within 10 percent of measured values. The mean absolute error for the spatial distribution of water levels for current conditions (as defined in the conceptual model) shall be reported as well as the mean absolute error for fitting the hydrographs and matching the magnitude of water-level variations. Temporal variations of larger known fluxes out of the aquifer (for example, springs and baseflow to streams) shall also be calibrated. The model shall reproduce the general distribution of water levels and the magnitude of water-level variations in the aquifer.

If the model does not perform well during the calibration period (in other words, if the model error is greater than 10 percent of the maximum hydraulic head drop across the study area), the calibration and perhaps the conceptual model shall be revisited to improve the fit. It is important that the performance of the model during the calibration period and the strategies employed to improve the fit, if necessary, be thoroughly documented as they offer insight into the uncertainty of predictions made by the model. It is unacceptable to select the option to “continue MODFLOW simulation even if convergence not achieved” in Groundwater Vistas. A detailed table summarizing the water budget for the entire model and for the individual layers shall be made and included in the final report. This water-budget table shall include:

- Recharge
- Gains or losses to surface water bodies
- Discharge to springs
- Other natural discharge (for example, evapotranspiration)

- Cross-formational flow
- Discharge to wells
- Changes in aquifer storage

This table shall include budget information for the steady-state model and transient model. The contractors shall also extract the water budget per county and per groundwater conservation district for the end of the transient calibration or the stress period chosen in cooperation with the TWDB. This information, as well as an analysis of how well the model simulates measured targets at the stress period per county, shall be included in the final report.

In addition, there shall be an accounting of the number of cells that go dry during a simulation, if applicable. The contractor shall have a strategy for addressing dry cells during calibration simulations. If the aquifer has not historically gone dry, then the aquifer shall not go dry during the calibration period. If parts of the aquifer have gone dry in the past but have subsequently re-saturated, then the contractor must have a plan for allowing cells in the model to re-saturate or remain saturated.

The steady-state and transient calibration models shall be contained in the same model (that is, include the steady-state model as the first stress at the beginning of the transient model). Including the steady-state model as part of the transient model ensures that any changes made to the model during the transient calibration will propagate to the steady-state model. It is important to verify that once the steady-state and transient calibration models are combined that sufficient stress periods are included to transition from little to no pumpage in the predevelopment steady-state to the transient calibration model. It is also important to confirm that steady-state has been achieved as changes are made during the transient calibration and propagated to the steady-state model.

3.4 Sensitivity analysis

After the steady-state and transient models are calibrated, a sensitivity analysis on each major parameter in the model shall be performed (see, for example, Mace and others, 2000; Anderson and Woessner, 1992, Figure 8.15). Sensitivity analysis quantifies the uncertainty of the calibrated model to the uncertainty in the estimates of aquifer parameters, stresses, and boundary conditions (Anderson and Woessner, 1992, p. 246) and is an essential step in modeling (Freeze and others, 1990). Sensitivity analysis assesses the adequacy of the model with respect to its intended purpose (ASTM, 1994) and can offer insight to the non-uniqueness of the calibrated model. Sensitivity analysis also identifies which hydrologic parameters most influence changes in water levels, flows to springs, streams, and rivers, and can identify parameters that justify additional future study.

Sensitivity analysis shall be performed by globally adjusting each model parameter and assessing its impact on water levels and fluxes (for example, springflow, baseflow, and cross-formational flow). Model parameters include:

- Horizontal hydraulic conductivity
- Vertical hydraulic conductivity
- Confined storativity

- Specific yield
- Recharge
- Pumping
- Hydraulic head assigned at any constant head and general head boundaries
- Conductance values for drains, rivers, general head boundaries, or any other packages for each layer

Model parameters shall be adjusted plus or minus 10 percent and plus or minus 50 percent from calibrated values and the mean error between the calibrated water levels and the simulated water levels at the calibration points for the adjusted parameter shall be determined (for example, see Anderson and Woessner, 1992, Figure 8.15). Where appropriate, the sensitivity of the model to order-of-magnitude changes in model parameters shall be done (for example, confined storativity). Results of the sensitivity analysis shall be presented as in the Mace and others (2000) report on the groundwater model developed for the Trinity (Hill Country) aquifer. A similar sensitivity analysis shall be done for transient simulations where the impacts of varying storage parameters on water-level fluctuations will be demonstrated. Sensitivity analyses on different conceptual models (for example, recharge, pumping distribution, and boundary conditions) are encouraged where appropriate. Additional sensitivity analyses to address sub-regional or local issues are encouraged (for example, a specific stream). Sensitivity analyses on groups of parameters (such as adjusting recharge and hydraulic properties together) are also strongly encouraged.

4.0 Documentation

Thorough documentation of the models is extremely important in ensuring their continued use. Each of the models shall be thoroughly documented and made available to the public upon completion of the project. Documentation shall include four major products:

- Source and derived information from the development of the conceptual model in an ArcGIS version 10 or 10.1 geodatabase format
- Source and derived pumpage information calculated for each model grid cell in an ArcGIS version 10 or 10.1 geodatabase format
- Model input and associated files in both MODFLOW-2000 or more recent MODFLOW (with TWDB approval) in ASCII format and Groundwater Vistas version 6.x format
- Final report in both Microsoft Word 2010 compatible format and Adobe Acrobat 10.0 PDF format of the conceptual model report

In addition to the discussion below, we have prepared data models in Environmental Systems Research Institute (ESRI) personal geodatabase format for the projects (Attachment 2). An optional ArcGIS geodatabase for organizing and storing all calibrated MODFLOW model grid cell parameters and time series variables is available (contact contract manager for details).

4.1 Software Requirements

All computer files and formats shall be 100 percent compatible with personal computer (IBM-PC) type systems. Electronic files may be physically shipped using digital video discs (DVD). In addition, files may be zipped with a self-extracting software program such as WINZIP. Contractors shall deliver three sets (on separate digital video discs) of all electronic files of documented source data and model files (when appropriate) used during the development of the:

- Draft conceptual report
- Final conceptual report and draft model/calibration report
- The final model/calibration report

Contractors shall deliver four hard copies of the draft conceptual report, eight copies of the final conceptual report, four hard copies of the final draft report, and then eight hard copies of the final report (see contract for any exceptions). All files and data shall be transferred to the TWDB in ready-to-use format. Formats of all computer files provided to the TWDB by the contractors shall be fully compatible with the widely distributed versions of the following programs:

- Word Processor Files—Microsoft Word (MS Office 2010)
- Geodatabases data—ESRI ArcGIS (version 10 or 10.1)
- Spreadsheet files—Microsoft Excel (MS Office 2010)
- Graphs, bar charts, pie-charts—Microsoft Excel (MS Office 2010)
- Internet ready reports in pdf format in parts not to exceed 10 megabytes—Adobe Acrobat (10.0)
- Turn-key models—Groundwater Vistas (version 6.x)
- MODFLOW 2000 or more recent versions—ASCII data files
- Scanned files—uncompressed TIFF (8-bit for black and white and 24-bit R.G.B. for gray/color with at least 300 dpi or greater, if needed, to resolve image resolution)

The contractor shall seek the approval from the Executive Administrator as to the compatibility of alternative software. Contractors need to provide Environmental Systems Research Institute (ESRI) compatible files for all geographic information system information. All drawings and graphs included in all reports shall be provided separately to TWDB in their native file format. In addition, all figures shall also be provided separately to TWDB in JPEG formatted files with 300 dpi or greater resolution.

4.2 Source information

Important products from the modeling studies include not only the models but also the source information used to develop the models. These source data have potential use beyond the initial groundwater availability models for groundwater conservation districts, regional water planning groups, groundwater management areas, TWDB, and other users to support ongoing management issues and research. Therefore, we expect to receive all source data used in the development of the model. For example, we expect to receive all point data used to develop spatially distributed parameters. If map information was digitized from an existing scanned or paper document, we expect to receive the final geographic information system files of the digitized map(s) with metadata documentation citing the source of the files. If information from geologic cross-sections within a published document is used, we expect a scanned image file or digitized vector file of the cross-section(s) with metadata documentation. The source data also allows alternative interpretations of parameter distributions to be investigated in future studies.

Source data refer to the tabular, point, line, polygon and/or raster information developed or used to create model input files. All the source data shall be delivered to the TWDB in the appropriate format (see Sections 4.1 and 4.4 and Attachment 2). Spatial information shall be projected into the groundwater availability modeling coordinate system with units of measure in feet prior to and during any spatial analysis (see Attachment 2).

Source data for the study area includes:

- Properly projected geographic information system feature datasets of the boundary of the study area including major towns and cities, county boundaries, major rivers and streams, major reservoirs, major roadways, regional water planning group boundaries, groundwater management area boundaries, groundwater districts, physiographic delineations, river basins, and model boundary
- Geographic information system raster and/or feature datasets of the topographic elevations in the study area (digital elevation model source data and the contours)
- Tabular data and geographic information system raster and/or feature datasets of average annual precipitation (including gage locations and associated time-series data)
- Tabular data and geographic information system raster and/or feature datasets of net lake or pan evaporation
- Geographic information system feature datasets of the surface geology
- Tabular data and geographic information system raster and/or feature datasets of the net sand maps, if applicable
- Geographic information system feature datasets of the major structural and tectonic features
- Geographic information system raster and/or feature datasets of the top and bottom elevations for each model layer
- Tabular data and geographic information system raster and/or feature datasets of the water-level maps
- Tabular data for the historical hydrographs
- Tabular data for the stream-flow hydrographs
- Tabular data for the springflow hydrographs
- Tabular data for the lake level hydrographs
- Tabular data for the hydraulic conductivity, transmissivity, and storativity
- Raw data and plots used to calculate hydraulic conductivity, transmissivity, and storativity
- Geographic information system raster and/or feature datasets of the distributions of transmissivity, hydraulic conductivity and storativity
- Tabular data for the historical pumping at the resolution used to develop the model input datasets
- Tabular data and geographic information system raster and/or feature datasets of population density

- Tabular data and geographic information system raster and/or feature datasets of the recharge rates
- Tabular data and geographic information system raster and/or feature datasets of historical pumping information
- Geographic information system raster and/or feature datasets of water levels for the steady-state run and the beginning, during the transient run at a time negotiated with TWDB, and end of the transient calibration run
- Tabular data of calibration targets including target name, GAM coordinate, model row/column/layer, related hydrogeologic unit, measured value, and associated stress period and date
- Geographic information system raster and/or feature datasets of final model parameters (e.g. horizontal hydraulic conductivity, vertical hydraulic conductivity, recharge, pumping rates) if different from distributions assembled during the conceptual model
- Any other data used to develop the model

Point data shall be delivered in two formats:

- Microsoft Access 2010
- ESRI Arc/GIS version 10 or 10.1

Interpreted data (for example, contoured data) shall be delivered in ESRI Arc/GIS version 10 or 10.1 format. Any information associated with a state identification number (such as the state well number for located wells and the water use group [WUG] number and related fields [county, basin, region] for water users) must maintain that association in the final databases (Attachment 2). All tabular data and geographic information system raster and feature datasets shall be delivered to the TWDB within the groundwater availability modeling source geodatabase schema provided to each contractor. The groundwater availability modeling source geodatabase schema defines file-naming protocol, database organization, and documentation of the tables, databases, and geographic information system spatial data (Attachment 2).

4.3 MODFLOW input files

All MODFLOW 2000 or more recent MODFLOW input files shall be submitted in ASCII format and the file format for Groundwater Vistas. The files for Groundwater Vistas shall also include ESRI geographic information system shape files of the:

- Model boundary
- County outlines
- Rivers, streams, reservoirs, and other hydraulic features simulated in the model

Future users shall be able to:

- run the model using MODFLOW 2000 or more recent MODFLOW from the command prompt with the files provided and
- run the model using Groundwater Vistas with the Groundwater Vistas files

provided.

4.4 Final reports

The final reports shall include the details of the conceptual model, input datasets, model construction, calibration, sensitivity analysis, and model results. There shall be two final reports for each modeling project—conceptual model report and model report. The final reports will be a reflection of the TWDB as well as the contractors and shall be well written, containing little to no spelling or grammatical errors. Final approved reports must follow Texas Board of Geoscientists guidelines (see http://www.tbpg.state.tx.us/index.html).

4.4.1 Report format and figures

Each section of the submitted reports shall address the data and analysis described in Section 3. Additional sections and subsections may be added to the submitted reports to address aquifer-specific issues.

Drafted figures shall be similar in design to each other and include a legend and a descriptive figure caption and must fit on 8.5 by 11-inch paper. If you use color figures, please keep in mind that the report may be photocopied or printed from the .pdf onto a black and white printer. For this reason, you should use symbols or patterns or make sure that colors print as different shades in grayscale. All interval or ratio data (data measuring continuous phenomena, with each color representing an equal interval) need to be displayed in a graded scale of a single color.

Minimum requirements for figures include:

- Figures shall be designed such that a black and white printout is readable and understandable
- Maps include a north arrow and a scale
- Figures and maps shall include legends showing related features
- Each figure has a caption that includes reference sources for the base map or the included information
- Figures must follow Texas Board of Geoscientists guidelines

Sources of data/base maps shall be clearly indicated on the figure or in the figure caption. Additional figures may be added as needed.

At a minimum, the final **CONCEPTUAL MODEL REPORT** shall include the following sections, subsections, and figures and is designed with the general public as the audience:

Executive summary:

Provide a brief summary of the conceptual model.

1.0 Introduction

Describe the importance of the aquifer to the region and provides a general outline of the modeling study and report.

2.0 Study area

Discuss study area and include the following maps:

- Maps of the study area showing major towns and cities, county boundaries, major rivers and streams, major reservoirs, major roadways, location of the study area within Texas or any bordering states (if applicable), and the model boundaries
- Map showing the location of the different Regional Water Planning Groups in the area
- Map showing the location of the different Groundwater Management Areas in the area
- Map showing the location of groundwater conservation districts in the area (documented with the date of the source reference)
- Map of the major river basins and major surface water features

2.1 Physiography and climate

See Section 3.1.1 and include the following maps:

- Map of the delineated physiographic areas
- Map of topographic elevation
- Map of climate classifications for the study area
- Map of average annual precipitation over the study area in inches per year (1981 to 2010)
- Map of average annual temperature over the study area in degrees Fahrenheit (1981 to 2010)
- Map with several plots of average monthly precipitation measured at rain gages in the study area in inches per year (1981 to 2010)
- Map of average annual net lake or pan evaporation over the study area in inches per year (1981 to 2010)
- Map of average evaporation
- Map of vegetation types (root depths if available or estimated)
- Maps of soil properties including infiltration (or permeability), water capacity
- Map of estimated potential and actual evapotranspiration, if available

2.2 Geology

See Section 3.1.2 and include the following maps:

- Map of the surface geology
- Maps of spatially distributed geologic information used during the modeling study (showing the control data if possible)
- Map of the major structural and tectonic features in the area

- Detailed stratigraphic chart of aquifers in study area
- Several geologic cross-sections through the study area

3.0 Previous work

Describe the previous studies of the Brazos River, the Brazos River Alluvium Aquifer and adjacent hydrogeologic units. Studies related to groundwater extraction, groundwater level, river flow, precipitation, and their correlations should be thoroughly investigated and documented. In the past, TWDB has developed several groundwater flow models for the major and minor aquifers in the region. These models may not include or explicitly simulate the Brazos River Alluvium Aquifer. However, the existing groundwater models and their associated data sources may be able to provide useful information to the Brazos River Alluvium Aquifer model. Thus, the existing models and related databases/files shall also be reviewed and investigated.

4.0 Hydrologic setting

Discuss the information compiled and analyzed for developing the conceptual model (as discussed in Section 3.1) in the following subsections:

4.1 Hydrostratigraphy and hydrostratigraphic framework

See Sections 3.1.3 and 3.1.4 and include the following maps/figures:

- Schematic of the geologic units in the study area and the hydrostratigraphic units used in the model - The corresponding model layer should be included in the final report. For example, the geologic age of the strata, group name, formation name, geologic description, hydrogeologic description (aquifer/aquitard) and the corresponding model layer should be provided
- Maps of top and bottom elevations for each of the model layers including the control points
- Maps of layer thickness for each of the model layers including the control points

4.2 Water levels and regional groundwater flow

See Section 3.1.5 and include the following maps/figures:

- Maps of the potentiometric surface for each model layer for the steady-state, the beginning of the transient calibration, during the transient calibration at a time agreed-upon with TWDB, and at the end of the transient calibration including the control points
- Several historical hydrographs demonstrating water-level fluctuations (including seasonal, if available) in the aquifer with a map indicating location of the wells

4.3 Recharge

See Section 3.1.6 and include the following map(s):

- Map(s) of estimated recharge rates, potential, factors, or coefficients

4.4 Rivers, streams, springs, reservoirs, and other surface hydraulic features

See Section 3.1.7 and include the following figures:

- Representative stream-flow hydrographs for the Brazos River and any associated streams or tributaries in the study area with a map indicating gage locations
- Spring-flow hydrographs if appropriate with a map indicating spring locations
- Hydrographs of reservoir levels if appropriate

4.5 Hydraulic properties

See Section 3.1.8 and include the following figures and maps:

- Histograms of hydraulic conductivity, specific yield (if appropriate), storativity/ for each model layer
- Map of hydraulic conductivity, specific yield (if appropriate), storativity for each model layer
- Net sand thickness maps, if applicable

4.6 Discharge

See Section 3.1.9 and include the following figures, maps, and tables:

- Bar chart(s) of yearly total historical groundwater usage
- Map of rural population density
- Tables of the historical pumping data according to major user group and summed over each county shall be included in the report

4.7 Water quality

See Section 3.1.10 and include the following maps:

- Maps of water quality (total dissolved solids and any other constituents of concern)

5.0 Conceptual model of groundwater flow in the aquifer

Describe the concepts and assumptions of the aquifer that were used to guide the construction of the model. These concepts should include (1) identifying the modeled layers and confining units, (2) describing the movement of water from recharge areas to discharge areas through the aquifer, and (3) discussing important controls on groundwater flow (for example, faulting, lithology, and boundaries). Please include the following figure:

- Block diagram showing the hydrogeologic units and summarizing the flows in the conceptual model and how the conceptual model was translated into the computer model (for example, see Mace and others, 2000, fig. 50)

6.0 Future improvements

Indicate where additional improvements could be made to the conceptual model in collecting more data or additional studies. Recommendations for how these issues could be addressed will be appreciated.

7.0 Acknowledgments

Acknowledge those organizations or specific individuals that assisted in the conceptual modeling project by supplying data, providing thoughtful discussion, or contributing more directly to the study.

8.0 References

All references cited in the report shall be included in the 'References' section following TWDB format.

At a minimum, the final <u>**MODEL REPORT**</u> shall include the following sections and subsections and shall be designed with a groundwater modeler as the audience:

Executive summary

Provide a brief summary of the model development and calibration.

1.0 Introduction and purpose of the model

Describe the importance of the GAM program, how the model relates to planning for groundwater resources, and provides a general outline of the modeling study and report. Includes the following maps:

- Location map of study area/related aquifer(s) within model domain

2.0 Model overview and packages

Briefly describe the conceptual model and the associated block diagram from the conceptual model report (see Section 5.0 of the CONCEPTUAL MODEL REPORT). If changes have been made since the conceptual model report, contractor must document these changes and provide data and analyses to support the changes. Contractor also needs to explain how the conceptual model is translated to the numerical model.

- Final block diagram showing the hydrogeologic units and summarizing the flows in the model and how the conceptual model was translated into the computer model (for example, see Mace and others, 2000, fig. 50) updated with any changes (from the conceptual model report), if needed.

Discuss the general attributes of MODFLOW including code, processor and packages (see Section 3.2). Include subsections for each of the packages used using the following as a guide, as applicable. Includes the following tables:

- Summary of model input packages and filenames
- Summary of model output files and filenames

All MODFLOW input and output packages should be included in a name file.

2.1 Basic package

Includes the following maps:

- Maps showing the location of active/inactive cells in each of the model layers and related hydrogeologic units

2.2 Discretization package

Includes the following table and figures:

- Table of stress periods with time interval and related year and/or month
- At least two cross-section figures (perpendicular to each other) showing the numerical layers and related hydrogeologic units

2.3 Layer-property flow package

Includes the following maps and tables:

- Map (e.g., raster image) of each of the property values for all model layers used by the layer-property flow (LPF) package
- Tables of statistic summary of all property values at model cells used by the LPF package and their comparison with the related field measurements and conceptual model
- If different zones are used for the same hydrogeologic unit, the summary table(s) shall also reflect the zones

2.4 Well package

Includes the following map and table(s):

- Map(s) (e.g., raster image) showing well location and if possible extraction/injection rate per model cell for each layer for the selected stress period(s)
- Table of total pumping (i.e., groundwater extraction) per county per stress period for each layer
- Table of total injection per county per stress period for each layer, if applicable

2.5 Drain package

Includes the following map and table:

- Map showing the drain locations and type of hydraulic features simulated by drains
- Summary table of drain heads and conductance values as well as associated model layer/row/column and hydraulic features

2.6 General-head boundary package

Includes the following map and table:

- Map showing the general head boundary (GHB) location and type of hydraulic features simulated by the GHB
- Table of GHB head and conductance values as well as associated model layer/row/column and hydraulic features

2.7 Recharge package

Includes the following maps and tables:

- Map(s) (e.g. raster image) of showing distribution of total recharge for the selected stress period(s). The associated model layers and hydrogeologic units that receive the recharge must be identified on the maps. In addition, different types of recharge shall also be presented on separate maps.
- Table(s) of total recharge per county per stress period for each type of recharges, if applicable.

2.8 Stream or river package

Includes the following maps and tables:

- Map(s) showing locations of streams or rivers in the model
- Table(s) of water level, riverbed elevation, stream flow as well as other input information for each of the streams or rivers in the model

2.9 Evapotranspiration (ET) package

Includes the following maps and tables:

- Map(s) showing distribution of ET rates and any other pertinent information
- Table(s) showing average root depths for vegetation types

For all of the input parameters used by the MODFLOW packages described above, contractor must document how the parameters are defined and if the parameters are consistent with the conceptual model. Contractor must contact the TWDB first before inconsistent parameters may be used for the model construction and calibration.

If other MODFLOW package(s) would be used, contractor shall first consult the TWDB and expects to follow the same guidelines as described above.

For all MODFLOW input packages, TWDB will not accept external files.

2.10 Output control file

- Contractor can use either words or numeric codes to specify the output control file.
- The output control file shall define at least head and cell-by-cell flux saved per stress period.
- If multiple time steps are used for a stress period, the last time step of the stress period should be used to save the model outputs.
- The budget files should be saved as non-compact format.
- The output control file shall be consistent with the name file if numeric codes are used.

2.11 Solver

Includes the following information:

- Type of solver
- Head change and residual convergence criteria
- The criteria shall be chosen small enough to ensure the volumetric mass balance for each stress period to meet the calibration goals as described in the "Model Calibration" section

3.0 Model calibration and results

This section should summarize the procedure/method used for model calibration and calibration results (see Section 3.3). Model calibration shall include both steady-state and transient conditions. Details shall be included in the sub-sections 3.1 through 3.6.

3.1 Calibration procedure

- Contractor shall state what measured or calculated targets are used for the model calibration.
- Contractor shall do a QA/QC on the targets and select the reliable ones for the model calibration
- Contractor shall provide reasoning if some targets are eliminated from the calibration process
- Contractor shall document calibration results separately for steady-state and transient conditions in the following sub-sections
- Contractor shall describe parameters adjusted during calibration of the model (for example, recharge, hydraulic conductivity, storativity, vertical hydraulic conductivity)

3.2 Model simulated versus measured heads

- Map(s) showing locations of head targets per model layer
- Scatter plots of simulated hydraulic head and measured hydraulic head for all head targets with statistic summary of residuals on the plots or in separate tables
- Scatter plot of simulated hydraulic head and measured hydraulic head per layer with statistic summary of residuals on the plots or in separate tables
- For transient model, scatter plots shall be used for selected stress periods approved by the Maps showing the head residuals at head target locations per layer for selected stress periods approved by the TWDB
- Histogram of the frequency of residuals in each model layer
- Hydrographs at head targets with both simulated and measured heads
- Maps showing the simulated head contours and flow directions superposed on measured/interpolated head contours
- Contractor must show that the calibration is not biased laterally and vertically, and the simulated regional groundwater flow is consistent with the measurement and the conceptual model
- Maps showing the change of water levels between pre-development and the beginning of the transient and the change of water levels between pre-development and the end of the transient

3.3 Model simulated versus measured fluxes

- Map(s) showing locations of flux targets (such as springs, seeps, etc.) per model layer
- Scatter plots of simulated versus measured flux for all flux targets with statistic summary of residuals on the plots and in separate tables
- Scatter plot of simulated versus measured flux per layer with statistic summary of residuals on the plots or in separate tables
- Hydrographs at flux targets with both simulated and measured fluxes

3.4 Model simulated versus calculated/measured discharges to Brazos River

Includes the following maps:

- Map showing gauge stations along the river, if applicable
- Summarize simulated versus measured discharge from the aquifer to the river

3.5 Model simulated water budgets

Also discuss water budget by county and groundwater conservation districts included in Appendix A.

- Table of steady-state calibration net water budget overall and summed per aquifer layer(s)
- Figures of transient overall net water budgets by flow component and subdivided by summed aquifer layer(s)
- Correlation between flow components should be presented and discussed such as groundwater pumping and discharge to the Brazos River

3.6 Correlation between pumpage and recharge

- Total recharge due to precipitation versus total pumping in the Brazos River Alluvium Aquifer
- Correlation between pumpage and recharge due to precipitation per county

4.0 Sensitivity analysis

See Section 3.4.

4.1 Procedure of sensitivity

4.2 Results of sensitivity analysis

- Sensitivity plots of how water levels or appropriate fluxes (for example, baseflow, springflow) are affected by changes in all aquifer parameters (see Mace and others, 2000, for the format of the plot) also include additional plots, as applicable, discussed in Section 3.4.
- Several hydrographs demonstrating the sensitivity of water-level and flux fluctuations to changes in important hydrologic properties of the model, also include additional plots, as applicable, discussed in Section 3.4.

5.0 Model limitations

Discuss the limitations of the model. A general description of where and for what the model is applicable is needed as well as a discussion of how assumptions might affect model results, especially how they relate to predictions of water levels.

6.0 Summary and conclusions

Summarize the modeling project and its results.

7.0 Future improvements

Indicate where additional improvements could be made to the model. Recommendations for how these issues could be addressed will be appreciated.

8.0 Acknowledgments

Acknowledge those organizations or specific individuals that assisted in the modeling project.

9.0 References

All references cited in the report shall be included in the 'References' section following TWDB format.

APPENDIX A

Water budgets by county, groundwater conservation district, and layer

APPENDIX B

- Tables including head target name, coordinate, well depth, modeled head, measured head, head residual, land surface elevation, and associated model layer/row/column/stress period/date
- Head hydrographs for individual head targets including measured values presented as dots and modeled values presented as line
- Tables including flux target name, coordinate (if applicable), modeled flux, measured flux, flux residual, land surface elevation (if applicable), and associated model layer/row/column/stress period/date/hydraulic feature
- Flux hydrographs for individual flux targets including measured values presented as dots and modeled values presented as line
- Other calibration results

The following units shall be used in all data presentations:

- Land area in square miles (mi^2)
- Water volume in acre-ft (ac-ft)
- Elevations relative to mean sea level (ft-AMSL)
- Demand and supply rates in acre-feet per year (ac-ft/yr)
- Stream flows and reservoir releases in cubic feet per second (cfs)
- Springflow in cubic feet per second (cfs)

- Pumping rates in gallons per minute (gpm) or million gallons per day (mgd)
- Recharge rates in inches per year (in/yr)
- Annual precipitation in inches per year (in/yr)
- Evaporation in inches per year (in/yr)
- Evapotranspiration in inches per year (in/yr)
- Hydraulic conductivity in feet per day (ft/d)
- Transmissivity in feet squared per day (ft^2/d)
- Conductance in feet squared per day (ft^2/d)
- Specific storage in units of inverse length using feet (1/ft)
- Recharge volumes in acre-feet (ac-ft)

Information may also be co-reported in other units such as metric equivalents.

4.4.2 Report deliverables

There are three times when TWDB shall receive electronic copies of data used for the modeling effort and the deliverable report for review:

- After completion of the draft conceptual model (report shall include Conceptual Model Report information listed in Section 4.4.1)
- After completion of the transient model (draft report shall include Model Calibration Report information listed in Section 4.4.1)
- After completion of the project (final conceptual and model reports shall include information listed in Section 4.4.1)

For the draft conceptual model report, and then later for the draft model report, the contractor shall deliver to the TWDB:

- Four (4) hard copies of the draft conceptual model report or draft model report
- Adobe Acrobat (pdf) file of the draft conceptual model report or draft report for posting on the TWDB web site (broken into parts not to exceed 10 megabytes each) and the Word 2010 format including figures.
- All the related documented source and derived data in the appropriate geodatabase (see Attachment 2)
- Model input files (for MODFLOW-2000 or later version of MODFLOW and Groundwater Vistas with the draft report deliverable)
- All computer programs (source code and executable) that are used during the conceptual model development

The Stakeholder Advisory Forum participants and the TWDB shall have two months to comment on the conceptual report. Stakeholder Advisory Forum participants and the TWDB shall have another two months to comment on the draft report. The contractor will have two months to address comments from the draft report (as well as the comments from the conceptual model review period) before issuing the final report.

At the end of the study, the contractor shall deliver to the TWDB:

- Eight (8) hard copies of the final conceptual and model reports
- Digital copies of the final conceptual and model reports including all figures (in Word 2010 format)
- Adobe Acrobat (pdf) file(s) of the final conceptual and model reports for posting on the TWDB web site (broken in part not to exceed 10 megabytes)
- Individual digital copies of each of the figures in the report (see Section 4.1 for details)
- All source and derived model data in digital format in the appropriate geodatabase (see Attachment 2)
- Model input files (for MODFLOW-2000 or later version of MODFLOW and Groundwater Vistas)
- All computer programs (source code and executable) that are used during the model development

It is important to us that the delivered reports are of high quality and that we receive the proper files. Consistent geologic, hydrologic, and technical terminology must be used throughout each report. Each report shall have an authorship list of persons responsible for the studies: firm or agency names as authors will not be acceptable. Final approved reports must follow Texas Board of Geoscientists guidelines (see http://www.tbpg.state.tx.us/index.html) and shall be sealed by either a Professional Engineer or Professional Geoscientist.

4.4.3 Presentations and web publishing

During the course of the project, the consultant will provide digital copies of presentations related to the model to assist us in promoting the modeling efforts and informing the public (in PowerPoint and Adobe Acrobat formats). Geodatabases, MODFLOW files, and the report may all be posted on the TWDB web site and will be distributed to interested parties on compact discs or digital video discs. TWDB will maintain centralized ownership and maintenance of the models.

5.0 Project management

The TWDB shall receive monthly letter reports for the duration of the modeling projects summarizing progress on the project. Any concerns should be documented in the progress reports and brought to the contract manager attention as soon as possible. The contractor shall also hold project review meetings with the TWDB at important points in the modeling process. TWDB may visit consultant on occasion to gauge progress on the project. These important points include:

- Beginning of the project
- After development of the conceptual model
- At key points during calibration and as often as needed
- After we have reviewed the draft report

Advancement of the project to the next phase of work described above is contingent on TWDB Executive Administrator approval of the efforts at each formal meeting. Each meeting will include discussions on the work that has been completed and the approach for the next phase of work. TWDB staff will also attend the Stakeholder Advisory Forums.

6.0 Project schedule

We expect that the conceptual model, all data collection associated with the development of the conceptual model, and the draft conceptual model report (this includes the 'Study Area,' 'Previous Work,' 'Hydrologic Setting,' and 'Conceptual Model of Groundwater Flow in the Aquifer' sections of the report [see Section 4.4.1]) will be completed by the date noted in the contract. The draft model report will be delivered by the date noted in the contract, as well as all associated data and model files.

7.0 References

Anderson, M. P., and Woessner, W. W., 1992, Applied groundwater modeling—Simulation of flow and advective transport: Academic Press, Inc., San Diego, 381 p.

Ashworth, J. B., and Hopkins, Janie, 1995, Aquifers of Texas: Texas Water Development Board Report 345, 69 p.

ASTM, 1994, Standard guide for conducting a sensitivity analysis for a ground-water flow model application: American Society for Testing and Materials Standard D5611-94e1, 6 p.

BEG, 1996, Physiographic map of Texas: Bureau of Economic Geology, The University of Texas at Austin, 1 p.

Domenico, P. A. and Schwartz, F. W., 1990, Physical and chemical hydrology: John Wiley & Sons, New York, 824 p.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, the U.S. Geological Survey modular ground-water model -- User guide to modularization concepts and the Ground-Water Flow Process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Fenske, J.P., Leake, S.A., and Prudic, D.E., 1996, Documentation of a computer program (RES1) to simulate leakage from reservoirs using the modular finite-difference ground-water flow model (MODFLOW): U.S. Geological Survey Open-File Report 96-364, 51 p.

Freeze, R. A., Massmann, J., Smith, L., Sperling, T., and James, B., 1990, Hydrogeological decision analysis- 1. A framework: Ground Water, v. 28, no. 5, p. 738-766.

Mace, R. E., 2001, Using specific-capacity data in hydrogeologic investigations: Bureau of Economic Geology, The University of Texas at Austin, Geological Circular 01-2, 44 p.

Mace, R. E., Chowdhury, A. H., Anaya, R., and Way, S.-C., 2000, Groundwater availability of the Middle Trinity aquifer in the Hill Country area of Texas- Numerical simulations through 2050: Texas Water Development Board Report.

McDonald, M. G. and A. W. Harbaugh, 1988, A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, variously paginated.

Prudic, D. E., 1988. Documentation of a computer program to simulate stream-aquifer relations using a modular, finite-difference, ground-water flow model, U.S. Geological Survey, Open-File Report 88-729, Carson City, Nevada.

Prudic http://water.usgs.gov/nrp/gwsoftware/modflow2000/ofr2004-1042.pdf

Scanlon, B. R., Dutton, A. R., and Sophocleous, M., 2002, Groundwater recharge in Texas: draft final report submitted to the Texas Water Development Board under contract number 2000-483-340 by the Bureau of Economic Geology, The University of Texas at Austin, variously paginated.

Shah, S.D., Houston, N.A., and Braun, C.L., 2007, Hydrogeologic characterization of the Brazos River alluvium aquifer, Bosque County to Fort Bend County, Texas: U.S. Geological Survey, Scientific Investigations Map 2989, 5 sheets.

Shah, S.D., and Houston, N.A., 2007, Geologic and hydrogeologic information for a geodatabase for the Brazos River alluvium aquifer, Bosque County to Fort Bend County, Texas (version 3): U.S. Geological Survey Open-File Report 2007–1031, 10 p.

Slade, R. M., Jr., Bentley, J. T., and Michaund, D., 2002, Results of streamflow gain-loss studies in Texas, with emphasis on gains and losses to major and minor aquifers: U.S. Geological Survey Open-File Report 02-068, compact disc.

Theis, C. V., 1940, The source of water derived from wells- essential factors controlling the response of an aquifer to development: Civil Engineering, American Society of Civil Engineers, p. 277-280.

Turco, M.J., East, J.W., and Milburn, M.S., 2007, Base flow (1966–2005) and streamflow gain and loss (2006) of the Brazos River, McLennan County to Fort Bend County, Texas: U.S. Geological Survey Scientific Investigations Report 2007–5286, 27 p.

EXHIBIT B

SCOPE OF WORK

ATTACHMENT 2:

DATA MODEL FOR THE GROUNDWATER AVAILABILITY MODELS

1.0 Introduction

To capture the various data types and sources that go into Groundwater Availability Models (GAMs), we have developed the groundwater availability modeling data model. A data model is a logical construct for storage, organization, documentation, and retrieval of digital information. The new groundwater availability modeling data model is built upon the Environmental Systems Research Institute, Inc. (ESRI) ArcGIS personal geodatabase (ESRI Press, 2004), which has been optimized by ESRI to manage related spatial and nonspatial data. The groundwater availability modeling data model consists of three principal data products expected from each groundwater availability modeling project: (1) the conceptual model source and unique derivative datasets within a Source geodatabase, (2) the source and unique derivative model grid pumpage values within a Pumpage geodatabase, and (3) the final MODFLOW specific input data files. An optional MODFLOW geodatabase will be made available for organizing and storing the final calibrated numerical model grid values (contact the TWDB contract manager).
The source and unique derivative datasets consist of natural and anthropogenic spatial features and associated time-series information, as well as any other spatial or non-spatial data used to develop the conceptual model and/or to generate numerical model grid values. The source and unique derivative model grid pumpage values consist of source data provided by TWDB within the Pumpage geodatabase and all derivative model grid pumpage values used for the final model calibration. The final MODFLOW specific data files consist of data files formatted for both MODFLOW-2000 or later version of MODFLOW and Groundwater Vistas. The grid values consist of the final grid-cell input data used for the calibrated steady state and transient numerical models.

Contractors shall use the groundwater availability modeling coordinate statewide mapping system to geo-reference all spatial data used in the modeling project. **It is extremely important and a requirement that all source data be projected into the groundwater availability modeling coordinate statewide mapping system prior to generating any derivative and/or model input data sets**. The groundwater availability modeling coordinate statewide mapping system provides complete statewide coverage with an equal-area projection that minimizes the spatial distortion of area. The projection parameters shown in Table A2-1 shall be used for the groundwater availability modeling coordinate statewide mapping system. The groundwater availability modeling personal geodatabase schemas will be preset with the correct coordinate and projection parameters so that spatial data with a predefined coordinate system will be automatically projected into the groundwater availability modeling coordinate system during data loading.

Table A2-1. Projection parameters to be used for the groundwater availability modeling coordinate statewide mapping system.

Groundwater availability modeling coordinate statewide mapping system

Projection :	Albers Equal-Area		
Units of Measure :	US Survey Feet		
Horizontal Datum :	NAD83	or	North American Datum 1983
Vertical Datum :	NAVD88	or	North American Vertical Datum 1983
Spheroid :	GRS80		
Longitude of Origin :	-100.00000	or	100^{o} : 00' West
Latitude of Origin :	31.25000	or	31^{o} : 15' North
Lower Standard Parallel 1 :	27.50000	or	27^{o} : 30' North
Upper Standard Parallel 2 :	35.00000	or	35^{o} : 00' North
False Easting :	1,500,000 (meters)	or	4,921,250 (US survey feet)
False Northing :	6,000,000 (meters)	or	19,685,000 (US survey feet)

1.1 Data content and organization

An enormous amount of spatial and nonspatial data will be generated by each groundwater availability modeling project. To facilitate management and public distribution of project datasets, the TWDB will provide each contractor with empty personal geodatabase schemas to organize and store source and derivative information for the conceptual model, and for model grid pumpage values. A personal geodatabase is a relational database that stores spatial and nonspatial data in a specialized Microsoft Access database.

ESRI ArcGIS (versions 10 or 10.1) software is required to work with personal geodatabases. The schemas will contain empty feature datasets, feature classes, object classes, tables, and raster datasets ready to be loaded with project data. The contractor shall use the geodatabase schemas for organizing, processing, and archiving all groundwater availability modeling project data. The groundwater availability modeling geodatabases are extendable, but prior written approval from the Groundwater Resources Division, Groundwater Availability Modeling Section Manager shall be obtained before any changes to the preset schemas may be made. The object of the Source geodatabase is to provide all basic data and metadata used to conceptualize the model, which along with written descriptions of derivation processes in the report, can be used to reproduce all input parameters for the gridded data in the model. The Pumpage geodatabase facilitates spatial distribution of pumpage from statewide TWDB datasets to a format that can be directly transferred to model grid cells. An optional MODFLOW geodatabase, intended to store all the input data needed to run the final calibrated steady state and transient groundwater availability modeling models with the MODFLOW-2000 or later version of MODFLOW code, will be made available upon request. If for any reason the source or derivative data is not compatible with the geodatabase schema, then that information shall be provided to TWDB in another format pre-approved by the Groundwater Resources Division, Groundwater Availability Modeling Section Manager that complies with software requirements noted in attachment 1, Section 4.1.

1.1.1 Source and derivative geodatabase schema

Source and unique derivative information shall be organized in the groundwater availability modeling Source Data Geodatabase. Source information is defined as original information collected and used to develop the final conceptual model of the aquifer system and to develop the gridded values used for the calibrated steady state and transient numerical models. Depending on the aquifer and methodologies used, we recognize that source and derivative data will be different for each project. Therefore, TWDB staff will review final contracts to identify the appropriate source and derivative data needed for the source geodatabase to reproduce critical model input. Vector spatial data shall be contained in feature classes that are organized into feature datasets. Each feature dataset contains thematically related point, line, and polygon feature classes. Nonspatial tabular data shall be stored in geodatabase tables or object classes, which are not contained within feature datasets but participate in relationships with corresponding spatial features. Raster data (such as interpolated or gridded surfaces; digital elevation models; satellite or other airborne imagery; and digitally scanned map graphics, logs, and cross sections) shall be managed in the geodatabase as raster datasets or raster catalogs. Raster datasets, although managed by the geodatabase, are stored outside of the geodatabase, effectively allowing a personal geodatabase to be larger than the two-gigabyte limit of typical Access database files. The geodatabase schema will also contain rules to constrain and standardize project data.

1.1.2 Pumpage geodatabase schema

Pumpage shall be processed and distributed spatially within the groundwater availability modeling pumpage geodatabase. The geodatabase maintains traceability between input source data (well records, master water-use tables) and output tables and spatial features. The geodatabase comprises tables, spatial features, and geoprocessing (GP) tools. Some input data, such as wells and land use, must be prepared by the contractor. The rest of the input data, such as master pumpage tables, are built into the geodatabase and ready to use. The geoprocessing tools calculate spatially distributed pumpage volumes per square mile of land use, distribute point specific pumpage to individual wells, and maintain key identifying fields for relating output data to corresponding input data. The geoprocessing tools may be run repeatedly using different input data sets each time. Spatial distribution of pumpage will occur within the geodatabase. Vertical distribution of pumpage to model layers and assignment of pumpage volumes to grid cells will occur outside of the Pumpage geodatabase. Note: other options may be considered with pre-approval by TWDB Groundwater Resources Division, Groundwater Availability Modeling Section Manager.

1.1.3 MODFLOW specific data files

The MODFLOW specific data files shall be organized into two primary directories or folders, one for MODFLOW-2000 or later version of MODFLOW standard ASCII files (Harbaugh and others, 2000) and the other for Groundwater Vistas 6.0 compatible files (Rumbaugh and Rumbaugh, 2004). Each directory or folder shall also contain: (1) a “files.txt” file containing a full list of each of the files in the directory or folder, (2) a “stress-periods.txt” file listing each stress period and its associated time length and date, and (3) a “readme.txt” file with a discussion of special instructions, tips, or information needed to use the files.

1.1.4 Model grid feature dataset

A model grid feature dataset shall be located within the Source and derivative geodatabase and consist of a polygon feature class of model grid cells and a point feature class of model grid cell nodes. The polygon feature class shall consist of square polygons representing a finite difference model grid with uniform sized cells no larger than 1/8 mile by 1/8 mile. The point features shall be centered on each of the polygon grid cells. A unique Cell_ID or relationship/index key consisting of a seven-digit integer data type and based on the layer, row, and column shall be used to link the polygon and point feature classes with any parameter values and time series variables. For example, a Cell_ID value of 2004025 would refer to the grid-cell or grid-cell node for layer 2, row 4, and column 25. Consequently, the maximum model grid dimensions for groundwater availability modeling projects are limited to the following:

Layers: 9
Rows: 999
Columns: 999

1.1.5 *MODFLOW geodatabase schema*

Using a geodatabase schema to organize and store model grid values is optional. The groundwater availability modeling MODFLOW geodatabase consists of a polygon feature class of model grid cells, a point feature class of model grid cell nodes, and tables/object classes for the final calibrated MODFLOW-2000 or later version of MODFLOW input parameters and for time-series variables linked with relationship classes.

1.2 Data documentation

All datasets used for groundwater availability modeling projects shall include metadata that documents the content, data structure, source(s), date(s), quality, and other characteristics of the data within the geodatabases. Metadata shall be created using the Federal Geographic Data Committee (FGDC) metadata editor within ESRI’s ArcCatalog. The TWDB-provided schemas include some basic metadata, which shall be extended by the contractor to completely document all source and derivative data. The contractor shall be responsible for making sure that all data is accurately documented and in compliance with the Federal Geographic Data Committee 's Content Standard for Digital Geospatial Metadata, Version 2 (FGDC-STD-001-1998) or later.

1.3 References

ESRI Press, 2004, ArcGIS 9 Building a Geodatabase: ESRI Press, 382 p.

Harbaugh, A. W., Banta, E. R., Hill, M. C., and McDonald, M. G., 2000, MODFLOW-2000, the U.S. Geological Survey modular ground-water model—User guide to modularization concepts and the Ground-water flow process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Rumbaugh, J. O., and Rumbaugh, D. B., 2004, Guide to using Groundwater Vistas Version 6: Environmental Simulations Inc., 366 p.